Wearable as Witness

Sensing and Categorizing Violent Forces in a Wearable System

by
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Submitted to the Program in Media Arts and Sciences,
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in Partial Fulfillment of the Requirements for the Degree of

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Abstract

The societal problem of physical abuse persists in part because of isolation and concealment. Emerging technologies have been adapted by abusers for methods of control and by victims for methods of resistance. This project examines the intimate position wearable technologies have with our bodies and explores the design of a wearable computer system that could record and document physical forces to the body in an effort to quantify the physical abuse. The system could potentially assist the victims in the process of self-realization by confronting them with the cumulative history of their experienced abuse, while anonymous publishing of this information could lead to more supportive communities for them. The proposed system is in the form of apparel or smart clothing utilizing large area, fabric-based pressure sensors to categorize and measure the intensity and patterns of forces to the wearer's body. The work of this thesis is to develop and to characterize the use of the garment to assess what data it can provide.

As textile-based user interfaces find their way into clothing, the opportunity for computers to identify physical abuse will become apparent. Although a computer system cannot understand the feeling of pain or the emotional suffering a victim feels, it should be aware of the presence of physical abuse for medical, legal or therapeutic reasons. This thesis will function both as a proof of concept and as a surveying stake to demonstrate a possible field of future investigation.

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CHAPTER ONE

Introduction

Physical abuse can take on many forms; there is child abuse, elder abuse and domestic abuse between partners. According to the Center for Disease Control (CDC) approximately 8.5 million incidents of Intimate Partner Violence (IPV) or domestic violence occur each year in the United States. These reported assaults consist of pushing, grabbing, shoving, slapping and hitting, and if left unchecked, often escalate to more serious violence if the relationship continues to be abusive. Physical abuse is not just a problem for adults in relationships. In a single year there were over 3.5 million investigated cases of child abuse, and with an aging population, elder abuse is becoming a growing concern [39]. The physically and mentally disabled are a particularly vulnerable group and can suffer many forms of abuse, even from their own caregivers. Physical violence is accompanied by emotional and psychological abuse of the victim as well as manifesting itself in depression, low self-esteem and anti-social behavior in the victim. The social consequences of physical abuse are devastating, resulting in increasingly strained relationships with friends and family as well as isolation from social networks. Often for victims, the abuse becomes a *"normal"* situation for them to live with. It becomes part of their everyday experience not only because physical abuse might be a frequent occurrence, but also because abusers will try to control every aspect of their life using whatever tools they encounter.

Technology, for better and for worse, is intricately woven into our society and culture. But how does technology relate to issues of abuse? An abuser will attempt to intimidate and control their victim with any method or tool available including any emerging technologies. Likewise victims and their advocates will do the same in an attempt to counteract any methods the abuser might adopt. In essence, there is a growing technological arms race between abuser and victim. It is my intention to investigate the role of wearable technologies in the next evolutionary phase of this battlefield.

The field of wearable computing began with ambitions of making computation more portable and more accessible in our daily lives. Researchers soon realized that wearables were in a prime position to gain an awareness of not just the physical environment of their user, but also the social milieu, and could thus facilitate social interaction and networking. Because of this, these social wearables will be confronted with the troubles and adversities in our lives, and some percentage will be exposed to abusive behavior. Since our clothing has a unique and intimate connection with our bodies, wearables designed with a sartorial method that makes use of this connection, are in a position to play a role in abusive settings by detecting and reacting to physical abuse. The physical forces on the body are the factor that defines when a situation goes from argumentative to physically abusive. Physical contact is the point at which many legal definitions of abuse can then be applied. It is this physical contact with the body that led us to explore the role of clothing and wearables as an intermediary between physical abuse and the outside world. Elaine Scarry definitively writes about the inexpressibility of pain and how it can simultaneously consume the individual and limit their social selves to the point that the only way for others to communicate with them is through a *"window of pain"*, that is, the pain itself is used as a vehicle to start communication [2]. How could a wearable computing system maintain and re-enforce social networks in these hostile environments? How can a system even detect if physical abuse is occurring?

The focus of this thesis is to take a step in developing a wearable system that can address some of the issues surrounding abuse by developing a clothing-based system to sense the physical forces that occur to one's body. Textile-based pressure sensors have been incorporated into clothing to be worn covering the wearer's body. Those forces detected can then be processed to determine what parameters can be reliably measured. The system can categorize those forces by location on the body, time the force occurred and the level of force exerted. The system is capable of keeping a record of the force data in an attempt to monitor the situation for assault and provide that data to the appropriate groups both in terms of state services and personal relationships. The thesis will provide the foundation of a wearable as a witness to abuse.

1.1 Thesis Overview

The following sections provide a general overview of the structure of the thesis and the themes it shall cover.

1.1.1 The Problem of Abuse

Abuse is a complex subject. It has been a constant social issue throughout history and crosses all cultural boundaries. Abuse is examined in such behaviors as shaken baby syndrome, child abuse, intimate partner violence and elder abuse. It consists of not just physical abuse, but includes verbal and psychological abuse, sexual abuse and various methods of controlling victims. Aside from the incredible emotional and psychological scars it leaves behind, abuse requires significant public resources to manage.

1.1.2 Tools of Abuse

Abuse is more than just physical violence; it involves complex methods of undermining the self-esteem of the victims in an effort to control them. Abusers will use any part of daily life experiences as methods to manipulate and control their victim. Categories of control are analyzed including economics, communication, mobility and children. Increasingly abusers are utilizing information and communication technology to perpetrate their abuse, for example, going online to engage in cyber stalking of their victims. In essence there exists a technological arms race between abuser and victim.

1.1.3 Tools for Victims and Survivors

Traditional tools for victims include women's shelters, support groups, therapists and social workers. There are however some non-traditional therapeutic methods that have evolved including development of specific languages and transformations of everyday tasks, like doing the laundry, into public awareness campaigns. We examine some of these non-traditional methods and follow that progression into the realm of information and communication technology as victims attempt to counteract the increasingly technological abusers.

1.1.4 Related Work

The review of related work focuses on sensor technologies implemented in body worn platforms. Most of the research work in this area has been done for medical or military applications, although some wearables have made it into the consumer market. The breakthrough of consumer clothing based user interfaces is highlighted as a potential means to introduce abuse sensing into the public realm. Also in this section, we will discuss how clothing has been used as a means for social dialogue and personal

expression. The form factor of clothing mimics our own body and thus becomes a natural method of communication for us.

1.1.5 Wearable Witness Design

The examination of documented physical abuse characteristics on the body were used to inform the design process of the *Wearable Witness*. The natural ability the body has for retaining force data in the form of bruises was examined and knowledge gained from that process applied to the textile-based sensor designs. When utilized in a clothing platform, textile-based sensor technologies are able to take advantage of the body's dynamics when confronted with an abusive situation. The *Wearable Witness* acts as a platform to test the many possibilities of detecting abuse leading to better human understanding.

1.1.6 Critique and Evaluation

The evaluation consists of two main parts. The first is an evaluation of the technical performance of the Wearable Witness prototype during simulated attacks involving the use of force. The second, conducted in conjunction with members of the abuse survivor community, is an evaluation and critique of the social implications of wearable technology in abusive situations. For the technical evaluation, a *Wearable Witness* prototype was constructed with capabilities to record the forces exerted on it. A pair of volunteers acted out abusive situations; one volunteer acted as the aggressor and one acted defensively while wearing the *Wearable Witness*. The forces used were greatly reduced from what might be expected in an actual confrontation to ensure the participants safety. The recorded data was then compared to known medical documentations of abuse. This was done to determine if the data produced by the *Wearable Witness* prototype would correspond to known abusive injuries and activities. For the social implications of the *Wearable Witness*, an evaluation and discussion by survivors of abuse and social workers was conducted as a qualitative study. They were given a summation on the *Wearable as Witness* research, as well as demonstrations of the prototype and sensor technology.

CHAPTER TWO

The Problem of Abuse

The concept of abuse is initially simple to define; it is to treat someone in a harmful manner. However, abuse as a social problem is an extremely difficult issue, often complicated by family dysfunction, poor communication skills, chemical dependencies and economic factors. It has been present throughout history and occurs in all cultures across society. In the past, abuse was so acceptable that English Common Law of the 18th Century allowed a husband moderate *"domestic chastisement"* of his wife to control her behavior. Although most legal systems have since outlawed domestic abuse, the problem still persists, largely in part because it is often viewed as a private matter between the couple. Most abuse then happens quietly behind closed doors with little if any outside interference. It is only the dramatic episodes that spill out into the public view that reveal its devastating consequences. For example, in modern day South Asian countries, ex-husbands and jilted lovers will seek retribution against their former partner by throwing acid in the woman's face, blinding or disfiguring them for life. In terms of child abuse we see similar attitudes of acceptance to physical force as a means of discipline. Corporal punishment of children by parents is still legal in many countries, but is highly debated as to whether it is an effective deterrent for children or simply an immediate release of anger for the parent. Does it lead parents to more violence, or is it teaching children at a young age that hitting can be ok, thus leading them to become potential abusers? It is evident that there are complex interpersonal relationship issues that surround each individual incident of abuse, and their effects on our communities can be both widespread and long lasting.

Violence between relationship partners has been found to take place not only within homes between married couples, but also it is a common occurrence with teens in the form of dating violence. The term Domestic Violence has been substituted with the broader term, Intimate Partner Violence (IPV) or simply Partner Violence. In general Intimate Partner Violence is the victimization of a person with whom the abuser has some

sort of intimate or romantic relationship [45]. It includes husbands abusing their wives and wives abusing their husbands. Each year there are approximately 5.3 million incidents of recorded intimate partner violence in which women are the victims and 3.2 million incidents where the man is the victim [9]. While both genders can become victims of intimate partner violence, women experience the abuse in a disproportionate amount. Male intimate partners are responsible for 22% of all nonfatal victimizations against females. In comparison, female intimate partners are responsible for only 2.9% of all nonfatal victimizations against males [40]. Male intimate partners commit 30% of all homicides where the victims are females, while female intimate partners commit just 5% of all homicides where the male is the victim [40]. Same sex couples experience intimate partner violence at approximately the same rate as their heterosexual counterparts.

2.1 Costs to the Community

Physical abuse coupled with its psychological impact has a profound effect on the victims in terms of their own personal development, future relationships and of course, safety. In broader terms the civic impact of these problems is a tremendous liability to social civic services. Police spend roughly a third of their time responding to domestic violence calls [45]. Studies also suggest that between 4% – 15% of visits by women to the emergency departments at hospitals are because of problems associated with domestic abuse [45].

Domestic abuse also affects the workplace. It is estimated that approximately 8 million days of work are lost each year from victims missing work due to injuries or intimidation by abusers. This is equivalent to approximately 32,000 full-time jobs [23]. The results are an overall loss in both time and productivity, costing United States businesses between $3 billion and $5 billion annually [7].

In the United States, the approximate 3.5 million investigated cases of child abuse each year result in significant costs in terms of both monetary expenses and labor. Every single case is assigned a social worker to investigate and conduct ongoing home visits. With incidents in which a child is physically injured, there are multiple costs: emergency medical care costs, investigation and foster care placement of the child, therapeutic and special educational costs. For example, infant victims of Shaken Baby Syndrome need immediate critical medical care. Expenses in the first years after an injury can surpass $1 million dollars [20]. The overall cost of child abuse nationwide was estimated at a staggering $94 billion annually [13]. This estimate calculated both direct costs, like those associated with medical care for injuries, and secondary costs, such as those associated with the higher rates of criminal behavior in adults who were abused as children.

Although putting a dollar value on the devastated lives left behind by abuse and its emotional turmoil may seem detached, the monetary cost provides a metric to compare to other civic expenses. Abuse is a widespread problem that requires significant public resources to manage.

A recent survey of victims of domestic violence showed that the majority of respondents would seek out assistance from civic services: 31.2% responded that they would go to the police for assistance; another 14.1% would go to a hospital, while 10.7% would find a local shelter. Only 10.7% would actually go to a family member for help. The remaining 30.8% did not know what they would do or simply would not seek assistance and try to deal with it on their own [44]. Even when women decided to visit the emergency room to seek medical care for abuse related injuries, emergency room physicians failed to identify abuse injuries correctly. Only one accurate diagnosis of abuse is made out of every 25 women who present with abuse injuries [45]. This could be the result of victims intentionally concealing the cause of their injuries from physicians. Victims will try to conceal or cover up their injuries for fear of retribution or embarrassment. They'll use make-up to cover bruises and wear extra clothing to hide other bodily injuries. Another more preventable reason for the low accuracy of diagnosing abuse is that medical staff is simply not directly asking if abuse was the cause. The end result is that approximately 23% of abused women had made multiple visits to the hospital with injuries 6 to 10 times before abuse was identified [45].

CHAPTER THREE

Tools of Abuse

The following are excerpts of personal stories from abuse survivors. They illustrate some of the methods abusers use:

> *He kept me home and fired me from my job. For the 1st time he hit me right across the face because I said I was leaving him. He dragged me into the dept. store and said we are going shopping so stop crying like a baby. He acted like it was nothing and I knew it was wrong but I did as I was told. I was 18 and he was 31. I thought an older man would be better for me but I was wrong.*
>
> *He would call my job all of the time and make me bring home a register receipt to prove what time I left. He held a gun to my head and said, "If you want to die, let's do it." He would hit me in the face all of the time. Everyone at my job knew he was mean but no one would help me.*
>
> *One night I went out with my friends like I always did on Fridays and when I got home he yelled and screamed at me for being out while he was working. I basically told him he needed to leave because it was not working out then he hit me across the face a couple of times. I got up and ran for the phone to call for help. He pulled it out of the wall. He kept saying why are you making me do this to you?* [31]

This survivor relays her experiences of not only physical abuse but also verbal and emotional abuse:

> *HE punched me with closed fists in my face, my stomach, and one day even gave me a black eye. He told me I was ugly, stupid, fat, and that he is the only one that is stupid enough to have any emotion towards me, so I became a bulimic "cutter"* [31].

Another survivor recounts her experiences with an abusive husband and how he would interfere with her family and friends:

> *When I would go visit my mom and dad I could only stay for ten minutes. I couldn't go have coffee with them in the mornings like I always had done. When I was gone longer than ten minutes Eddie would start pushing me around and he would grab my upper arm and drag me to the bedroom, that's where he always would start beating on me. Eddie would bruise my arm every time he grabbed me like that.*
>
> *I was outside talking to my neighbor and I had been out there for about thirty minutes and Eddie came out and told me. I had a phone call and I told him I didn't hear the phone ring and he made up some story as to why I didn't hear the phone, so I went in to answer the phone and I get in the house and there was no one on the phone, he told me they hung up. Eddie used this type of stuff to get me away from anyone I might confide in.*
>
> *I couldn't go to my family about what was happening because he told me he would go after them if I ever told them what was happening. So to save them I had to keep quiet* [31].

Intimate Partner Violence consists of a pattern of coercive behavior used by one individual, the abuser, to maintain power and control over another individual, the victim, in the relationship. The tactics used by the abuser include psychological abuse, sexual abuse and physical abuse:

Psychological abuse includes threats of physical harm to the victim or others associated with them such as friends, family and children, intimidation, degradation, humiliation and ridicule, usually with name calling. Stalking may occur during a relationship, or during and after a relationship has ended.

Sexual abuse may include nonconsensual or painful sexual acts.

Physical abuse includes assault with weapons, pushing, shoving, slapping, punching, choking, kicking, holding, and binding [45].

These episodes of abuse can be sporadic or occur on a regular basis. Each episode increases the potential for more serious consequences [45]. Often but not always, abusive relationships will begin with signs of coercive and controlling behavior. Attempts at both physical and social isolation of the victim are made. For example, the abuser denies the victim the use of a car to visit friends or makes communication with them

difficult. The abuser seeks to control the person they are victimizing, and physical abuse is merely one tool in an ever evolving arsenal. To the abuser anything and everything becomes a possible means of control. The basic necessities of everyday life can be turned into instruments of control.

We can attempt to categorize these methods to help better understand the tactics involved.

- Communication: Abusers will call to check up on a victim or harass them at home or while at work with verbal abuse. The billing information for telephone or cell phone accounts is kept solely in the abuser's name allowing them access to the corresponding call history in order to monitor with whom the victim is communicating.

- Economic: Abusers will often not allow the victim to keep credit cards or any bank accounts in their name. They will make sure any accounts are held jointly so that they can control the money and thus limit the victim's freedom. Getting the victim into debt or causing them to lose their job is another economic tactic.

- Physical Confinement and Mobility: Sometimes an abuser will lock the victim in a room or house essentially keeping them in a state of captivity. In addition, they will seek to confine the victim by moving far away from family and friends attempting to isolate them from any type of social support structures. Abusers will deny access or do damage to a victim's car to limit their mobility. They will also specifically create situations that endanger the victim, like abandoning them late at night in remote or unsafe areas without a means to get home.

- Children: Children are often used as pawns to leverage control. Abusers will threaten consequences like, *"If you leave me I'll get sole custody of the kids."* Even worse, they imply that if the victim leaves the children will be harmed. Pregnancy is often manipulated to make the victim vulnerable and more dependent on the abuser.

All these actions are designed to maintain control of the victim and take advantage of common everyday mechanisms and systems. Emerging technologies that filter into our everyday lives are then susceptible to being co-opted for abusive means within

relationships. This has become most prevalent with younger generations that involve Information and Communication Technology (ICT) in numerous aspects of their social lives and relationships.

3.1 Technology and Abuse

The Journal of American Medical Association reported that dating violence is more common than previously known and affects a younger age group than thought. A comparison of intimate partner violence rates between teens and adults reveals that teens are at a higher risk of intimate partner abuse [34] Females ages 16 – 24 are more vulnerable to intimate partner violence than any other age group [41]. The abusers and victims are increasingly part of a generation that has grown up with information and communication technology as an integral part of their lives. They have grown up with cell phones and the Internet, email and computer games. It then should come as no surprise that these technologies will be used both by abusers to perpetrate abuse as well as the victims to seek help or therapeutic assistance.

A recent survey of teens showed that one in three who were in intimate relationships stated that their partners had text messaged them between 10 and 30 times an hour asking who they were with, and where they were [14]. These are the signs of a controlling partner and the beginnings of an abusive relationship. These signs would present themselves in other modes of communication between the couples too, but it is the technology and immediate access of mobile communication, that when enabled as a controlling technology, becomes alarming.

> *Shaina Weisbrot, now a sophomore at Rutgers University, says as a teenager she was in a controlling relationship that eventually turned violent. She recalls staying on the phone until 5 a.m. some nights, arguing with her boyfriend. "I'd be in my room. I'd pretend to be sleeping. I'd shut the lights and I'd be quiet, and no one would know the difference because all you had to do was hide your cell phone* [14].

One recent survey found that one in three teen girls in a dating relationship have experienced feeling fearful of their partner [17]. As many as one in five female high school students reported actual physical or sexual abuse by their partner [34]. The phenomenon of teen dating violence is proving to affect a younger age group, and researchers are just learning its full impact. It is significant to note that this segment of the population is an *"always online,"* information and communication technology generation,

having grown up intimately knowing the internet and mobile communication technologies. It is then obvious to see abuse going online using instant messaging, email, on websites like Myspace.com and cell phones.

Methods for online abuse have been present since the early days of online message forums and discussion boards. Users would send or post frequent and numerous insulting messages to other users with whom they are disagreeing or arguing. This aggressive message posting act was called *flaming*. Entire forums could be overtaken in a *flame war* and eventually have to be shut down. The basic practice of using online venues for abusive and intimidating behavior has evolved, and in the context of intimate partner violence, has become a new arena where the abuser and victim struggle for personal power.

The popularity of social-networking sites has made an increasing amount of personal information publicly available. Abusers will visit personal blogs and Myspace.com pages to post derogatory messages and to track or to monitor their victim's lives and social contacts. Even websites devoted to assisting victims of abuse, with information on shelters or legal guidance, need to take precautions against the technical sophistication abusers have and are willing to use. The websites will often carry the following warnings and technical instructions:

> **** IMPORTANT NOTE FOR YOUR SAFETY***
>
> *An abuser may be able to tell which Internet sites you have visited on your computer. The safest places to find information on the Internet are at a local library, a friend's home computer, or at work.*
>
> *Most Internet browser programs (Internet Explorer, Navigator, AOL, and others) create a "history file" that shows a list of what has been viewed on your computer. If you feel you might be in danger if someone discovers that you have visited this site, make sure to delete the history file and "temporary Internet files". Do not save, "bookmark", or save as a "Favorite" risky pages in your browser or other Internet software* [1].

Abusive behavior has followed victims online, and we can reasonably predict that abusers will migrate their methods to any emerging field of technology. From the victim's perspective there will constantly be the need for tactical responses to this escalation in misuses of technology. It seems essential then to consider the theme of abuse in technology research and development.

CHAPTER FOUR

Tools for Victims and Survivors

Just as abusers will adopt techniques of control around everyday systems, victims and the support organizations that assist them have developed their own counter-systems. The first women's shelters were initially setup in England and the United States in the late 1960s and early 1970s by grassroots women's movements. Their focus was to offer a refuge for women who experienced domestic violence and needed a safe place to stay away from their abusive partners. There are currently around 2,000 shelters in the United States [24]. Some are coupled with larger institutions that conduct informational campaigns and other outreach programs. Unfortunately there are still not enough shelters, and many have a 30 day stay limit. During this time, the women are expected to recover, to find work in order to support themselves and their children and to locate a place to live. In some areas, shelters are so crowded that women end up being turned away.

State and federal legislation has been among some of the most important tools in the civic response to intimate partner violence. The State issues restraining orders and no-contact orders that prohibit the abuser from having any contact with the victim including phone calls, mail or third party communications. However, specific Federal funding was not made available to women's shelters, victim advocates or training programs until the *Violence Against Women Act* was passed by Congress and signed into law in 1994 [42]. The law not only provided much needed funding, but also created new strategies to fight the problem. For example, it allowed for the extension of the authority of restraining orders across state lines to hinder interstate spousal abuse and stalking. New Federal laws prohibit gun possession by any persons convicted of a domestic abuse crime [6]. In addition to the shelters, legislation and information campaigns, alternative methods of outreach and therapy have been developed, some with institutional support and some with spontaneous inventions by communities. These methods have been culturally diverse, and some community inventions stretch far back into the history of oppression.

Take for example, Nushu, translated to *"female writing"* script. It was invented by women for women as a secret language during the 15th Century in Hunan's Jiangyong County, in south central China. For hundreds of years the women were prevented from learning written Chinese, but they still endeavored a way to express themselves once they were married and forced to move away from their family and friends. The script was used in the form of embroidery patterns on clothing to discreetly communicate to *"sworn sisters"* their hopes, joys and sorrows without men's knowledge [16]. It helped alleviate the isolation in their lives because they had found a way to communicate their feelings [48].

Figure 1. Shirts decorated and displayed as part of the Clothesline Project.

Clothing has also been used as a method of social intervention and victim expression, as in the Clothesline Project founded in Cape Cod, Massachusetts **Figure 1**. The project was started by a group of women who wanted to transmute the pain of domestic violence into an educational tool to help heal and break the silence associated with abuse. The concept is for survivors, family members and friends to decorate shirts with their own words and pictures in order to tell their personal stories. The shirts are exhibited on clotheslines for public viewing and discussion. This idea originated from the following tradition:

> *Doing the laundry was always considered women's work and in the days of close knit neighborhoods women often exchanged information over backyard fences while hanging their clothes out to dry* [8].

Various traditional social programs and organizations are available to victims – as discussed previously – but more innovative approaches are being attempted. The pervasiveness of physical abuse has produced some unexpected means of intervention. *Cut It Out* is a program that seeks to educate and train salon professionals in how to raise awareness about domestic violence, and how to refer their clients to the appropriate

domestic violence resources in a safe and secure manner [11]. What differentiates *Cut It Out* from other awareness campaigns is that the salon has been identified as a *"safe space"* for women. It is a place they often visit on a regular basis without their abusive husbands, and it allows them a certain freedom and openness to discuss their lives.

> *Salon professionals are experienced listeners and it is not uncommon for women who are experiencing abuse to confide in them. In addition, the salon may be one of the few places a battered woman can go without the abuser* [12].

While passing out emery boards with abuse hotline numbers on them while blow-drying may seem strange at first, the social complexities of abuse dictate the need for flexible responses and innovative methods. It is with this mindset that the role of emerging technologies, such as wearables, should be considered, because victims and their advocates are no strangers to incorporating new technologies into their arsenals when presented with the appropriate opportunity.

4.1 Victim Technology

We have reviewed some of the traditional and not-so-traditional methods victims and advocates are taking to confront abuse, and we have seen how abusers will pursue and co-opt emerging technologies in an effort to continue their control over their victims. I argue that this is a technological arms race between abuser and victim. If my hypothesis is correct, then we should see victims start to take control of some technologies to counteract their abusers' efforts. In fact we do see this counteraction; technologies are being utilized by the victims in a therapeutic manner to help them cope.

Mobile phones are seemingly a ubiquitous part of our everyday life. We've seen how this always on, always connected form of communication can be manipulated by abusers to monitor, harass and threaten their victims, but there is of course a counter response. All mobile phones are capable of calling emergency 911 services regardless of whether or not the user has purchased a service plan. This unique technical feature has led many women's shelters and organizations to develop *"donate a cell phone"* programs. Used mobile phones are collected and distributed to victims of abuse who may encounter an emergency situation. While mobile phones have gotten less expensive since they were first introduced into the consumer market, there is still a need to distribute old phones to those who need them. The Verizon HopeLine® program, founded in 1995, began with providing voicemail boxes to the homeless in an effort to help them *"get back on their feet"* by providing a means for potential employers to get in contact with them. The

program evolved to include, and then focus specifically on, victims of abuse living in shelters. The program progressed into providing used cell phones to victims for emergencies [43]. Now that many cell phones are more affordable, the HopeLine® program recycles old phones for batteries, or re-furbishes them for re-sale. The company then donates the proceeds as cash grants to shelters. Over the years the program has been very successful collecting some 3.5 million phones, distributing more than 40,000 phones with airtime to victims of domestic abuse and awarding $3 million in grants to abuse agencies and organizations [43]. Verizon, as a large telecommunications company, might have started the program to increase their public image but it was with the involvement of Camille Murphy, then president of the National Association of Commissions for Women, that the appropriate niche for the technology was found. It is the lobbying efforts from individual advocates and shelters that may hold the best opportunities to transform or influence a technology to become useful to victims of abuse. In the same manner, environmental groups will lobby corporations for more green policies; domestic violence advocates should lobby technology companies to consider their technologies' role in aiding victims of abuse.

Responding to the growth of the Internet in the 1990s, women's shelters and programs embarked on a series of new responsibilities by founding online educational and informational portals. These websites act as guides to important legal and survival information, and spawned online communities of advocates and abuse survivors offering emotional support and advice. Websites sponsored by women's organizations and shelters are among the best sources for helpful information and online support. The communities developed around those sites have currently spread out to include many blogs that express more personal accounts and stories. There are however unexpected technologies being co-opted to address abuse. Take for example the computer game The Sims™ by Electronic Arts.

Figure 2. Images of abuse acted out in the Sims™ family album.

The Sims™ is a simulation game that lets players live out the daily activities of virtual people called Sims™. As a Sim™, the player can simulate working various jobs, buying virtual houses and having relationships with other Sims™, recreating things you do in real life, only virtually. Sims™ players are using the in-game Photo Album feature, originally intended to document and share the lives of the players' Sims™ characters, to act out and portray serious social and emotional traumas **Figure 2**. They are using the Sims™ characters to relieve some of that emotional weight and to share their experiences in this online format to help educate others. The Sims game has in fact become a therapeutic tool [37]. When Will Wright, the game's lead designer, was asked about the therapeutic phenomenon of the Sims™, he recalled one particular album.

> *…one of the most memorable albums told the story of a woman's abusive relationship and how she eventually got out of it* [37].

So though it may come as a surprise to many people – and the game developers themselves – that the games have been adopted for these unintended purposes, it is a significant revelation that certain technologies are in a prime position to offer assistance, if only they were identified. A 2006 Nielson Entertainment study estimated 117 million active gamers in the United States, with 56% of them playing online, 64% are women. Teens are spending approximately 7 hours per week in social gaming activity [36]. With the increasing popularity of Massively Multiplayer Online Games, like World of War Craft, and the online social communities that spring up to support them, game companies should consider including in-game abuse shelters or awareness campaigns in their future productions.

We have seen how tools for victims and survivors have evolved over time to counteract the methods and tactics of their abusers. Victims have adopted techniques around language, clothing and even personal grooming in an effort to alleviate the difficulties of living with abuse. They are engaged in an ongoing arms race in which any emerging technology can be adopted to assist them. We saw previously how cell phone communications and equipment were used as methods of control and abuse. We have also witnessed that through the efforts of victim advocates lobbying the telecommunications companies, those same technologies became positive tools in the struggle against abuse. The growing popularity of online gaming has seen victims of abuse spontaneously transforming their gaming experience into a means of relaying personal stories of abuse. The recent growth of online gaming has created a sizable population of players who spend numerous hours engaged in virtual worlds and

environments. In fact, some victims of abuse have spontaneously transformed their gaming experience into a means of relaying their personal stories. The level of interest and activity in gaming represents a significant opportunity and place for victim outreach through an emerging technology.

CHAPTER FIVE

Related Work

Abusive situations like those demonstrated in relationships exhibiting intimate partner violence are emotionally charged. They also present severe difficulties for intervention and data collection. In 2002 the Center for Disease Control (CDC) released a report entitled*: Intimate Partner Violence Surveillance: Uniform Definitions and Recommended Data Elements* [10]. In general the report is meant to help lay guidelines for survey data taken from victims. However the need and existence of such a report as late as 2002 is symbolic of the lack of civic effort to collect information about the victims of IPV and the level of violence confronted in their lives. This lack of information limits the ability to gauge the magnitude of violence against such victims in relation to other public health problems.

Although there has been little work attempting to insert data collection techniques into physical abuse situations, there are other areas in which data collection of bodily violence has been applied, and critical information has been revealed. For example, fifty football players at Virginia Tech University, the University of North Carolina and the University of Oklahoma wore sensor-equipped helmets during their season **Figure 3**.

> *Data from last season revealed fairly shocking statistics. The 38 football players wearing the helmets were struck in the head 30 to 50 times per game and regularly faced blows similar to those experienced in a car crash* [25].

On average the forces experienced were around 40G, roughly equivalent to a boxer's punch, while the more severe forces were measured at 120G, closer to those experienced in a car crash [4]. It is commonly known that football is a dangerous sport, but the collected sensor data gives us a specific metric that allows us to make an analogy between the forces in football and the forces in a car crash. This helps us to judge the severity of the situation and the potential physical injuries that might be incurred. Trainers

and medical staff are considering using the technology to watch for potential concussions during game play.

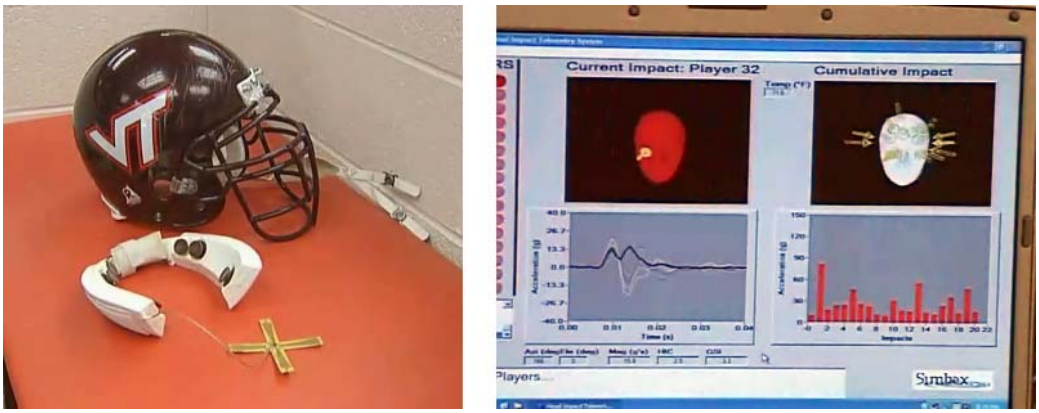

Figure 3. Virginia Tech helmet with accelerometers and data visualization software.

In the same way that the football helmet data could be used to justify closer medical supervision, detailed data on the physical forces of domestic abuse could convince legislators to devote more resources towards victim support groups or more medical programs for victims. Additionally, the need for victims to seek medical assistance on their own would be more apparent to them if they knew that the force of the abuse they received was equivalent to a twelve round boxing match, and this amount of force could cause brain trauma.

From a legal standpoint, more detailed data could help during the restraining order process and custody decisions. Emergency restraining orders can be granted without much interrogation by simply filling out paperwork, but they are *only good for 10 days*. A restraining order for a year needs to be brought before a judge, and it is at this phase the victim is asked to present information as to why the restraining order should be granted. Detailed physical abuse data may be viewed more seriously by a judge, as opposed to personal testimony that could be highly emotional or opinionated. Collecting quantifiable evidence in abuse situations can help in prosecuting cases, but that isn't the only reason that abuse victims are often instructed to document their experiences by, for instance, keeping a journal. Detailing the actual situation could potentially help in retelling the story and sharing the experience with others for therapeutic reasons.

5.1 Why Clothing?

There are various traditional methods by which one could attempt to document and record physical abuse. For example, video surveillance could be installed within a home

or even attached to a person. Often video surveillance is considered too intrusive, so a more conducive monitoring method would be needed. The clothing form factor is familiar to everyone. It is with us constantly day and night, acts as our second skin and conveys social messages. As we have previously seen with the Nushu embroidery and the Clothesline Project, there is a rich and unique history and culture of using non electronic or non-computational wearables such as traditional apparel or woven textile forms to be expressive. In *"The Body in Pain"* Elaine Scarry discusses the transformation of body into voice. The body and all its experiences can become communication [32]. Clothing then becomes a medium or conduit through which the body can speak. This is what I refer to as the sartorial method for wearables – apparel based systems that exploit the unique and intimate connection clothing shares with our bodies in order to communicate. Another reason for focusing on clothing as a method for abuse data acquisition is the potential to build off of other wearable technologies, like textile-based user interfaces on apparel that are beginning to enter the consumer market place. Our clothing has a unique and intimate connection with our bodies. It is therefore in a position to play a role in abusive settings by detecting and reacting to the physical abuse.

5.2 Unintended Technologies in the Marketplace

More and more sensors are being built into everyday products; even laptops can sense trauma [15]. The Apple® Powerbook laptops include a motion sensor (accelerometer) that locks the head of the hard drive if the machine were dropped. Of course, once a technology is released into the public, the public has the natural tendency to tinker and re-configure the technology for unintended uses. Software engineer, Amit Singh, was able to access the information the motion sensor provided, and turned it into a novel interface capable of opening programs by shaking or shimmying the laptop. Subsequent hacks to the motion sensor allowed an onscreen marionette to be controlled by tilting the laptop to and fro [38]. This is simply an illustration of industry motivated sensor integration for one purpose being reconfigured for alternative purposes. Re-appropriating sensors that may come onto the market in wearable designs will certainly be manipulated for alternate purposes. Simply put: Abuse recognition should be considered as one of those uses. As clothing becomes increasingly informationally aware, it will be important for victim's groups to lobby designers and manufacturers to address physical abuse detection.

In 2003 Burton Snowboards in collaboration with Apple® introduced one of the first affordable jackets with an integrated method for controlling an Apple® iPod.

Subsequently, there have been many other iPod jackets that have reached the market, and even a pair of Apple® iPod lederhosen with controls located on the hip and outer thigh area has been manufactured **Figure 4**. It still remains to be seen whether these wearables will find a permanent place in our wardrobes or simply be a fad. The Burton Amp was significant not only because it is arguably the first commercially affordable wearable, in terms of apparel, to hit the market, but also because it is a perfect example of its electronic sensors having the potential to do more than that for which they were designed. The fabric-based sensor technology used in the sleeve controls for the Burton Amp utilize quantum tunneling composite (QTC) sensors, and although they are small and designed to sense the pressure from a finger press, it is a short leap to re-appropriate those same sensors to detect extreme impacts or grabbing associated with physical abuse.

Figure 4. Sleeve detail of the iPod Jacket and iPod lederhosen.

The more textile-based user interfaces that find their way into our clothing, the more likely an abuse sensing system could access those sensors, so abuse sensing might evolve as an add on to other wearable systems. This works particularly well because a garment or wearable designed with the specific purpose of assisting victims of abuse may in fact psychologically cast the wearer into a victim's mindset or role. An ideal design would have to empower the wearer. Ultimately, all wearables should be built with an understanding of abuse and the ability to initiate therapeutic or other countermeasures.

5.3 Textile Technology

While there have been no previous projects in wearables regarding physical abuse, there has been work done to create textile-based sensors in the domains of military and medical applications.

The Smart Shirt Project was developed at Georgia Tech and originally funded by the Department of Defense under the Defense Advanced Research Projects Agency (DARPA). The textile is composed of optical fibers and conductive fibers coupled with other discreet sensors to monitor heart rate, EKG, temperature, respiration and other vital functions. In its initial development the shirt was able to detect bullet wounds, presumably by detecting punctures or breaks in the fibers **Figure 5**. The garment is also suited for medical applications as a means to monitor various bio-physiological responses of patients. A version of the suit was tested with infants to monitor for sudden infant death syndrome (SIDS) **Figure 6** [3].

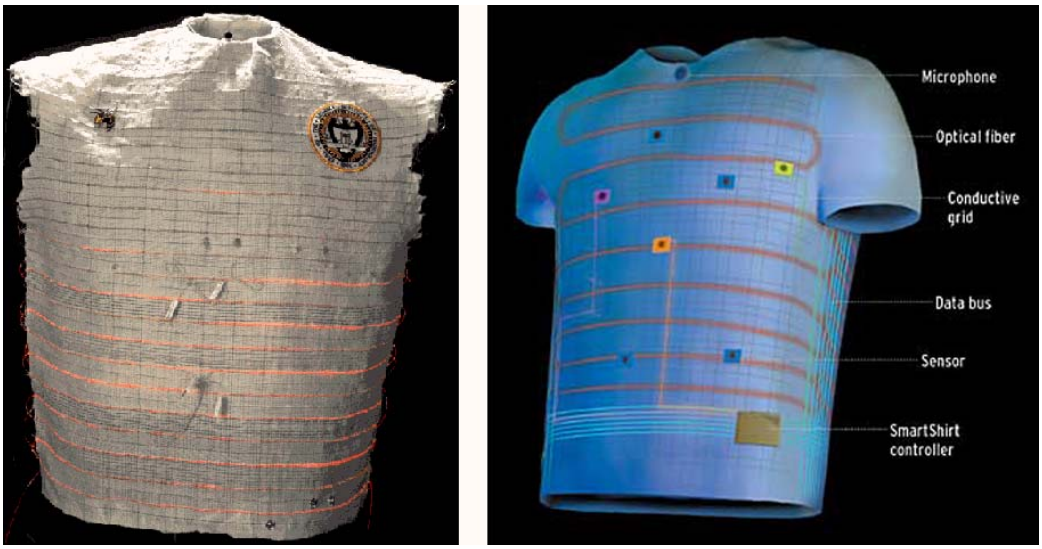

Figure 5. Smart Shirt project developed at Georgia Tech.

Figure 6. Infant Smart Suit capable of detecting SIDS.

The Smart Shirts developed at Georgia Tech do not sense external forces to the body unless the optical fibers are broken and in that instance only detect the puncture and do not measure the force. However there is research into developing sensing textiles that can sense force and thus, blunt force trauma on the body. A textile based capacitive pressure sensor was developed at the University of Bologna in Italy by creating a sandwich of conductive fiber columns and rows separated by an elastic synthetic foam. The elastic foam acts as a dielectric material and thus creates an array of capacitors between the columns and rows. When the foam is compressed, the coupling capacitance changes between the columns and rows of the textile [33]. This technology could potentially be used to detect forces of abuse, but no such materials are commercially available as of yet and constructing them would require certain weaving expertise and equipment.

Figure 7. Soldiers experience many forms of force and impact during operations.

Zephyr Technology of New Zealand is currently developing smart fabric sensors capable of being imbedded into garments, specifically for military applications, to measure and detect collisions and ballistic impact **Figure 7**. Their goal is to add the ability to monitor a soldier's injuries in order to respond quickly with the appropriate medical attention. No specifications about the technology are publicly available [50].

In the consumer market, clothing-based user interfaces have begun to make an appearance and are anticipated to increase in their scope and availability. The previous examples represent a realm of wearable technology that focuses on body located sensing capabilities built into textiles for entertainment, medical and military purposes. The *Wearable Witness* follows this same clothing-based approach building on the sartorial method of wearables by attempting to understand the relation of abusive force to the body.

CHAPTER SIX

Wearable Witness Design

The *Wearable Witness* is a clothing-based wearable system building on current resources and capabilities in wearables research including textile-based sensors developed for body monitoring in the military and medical fields. Throughout the development of the *Wearable as Witness* project social workers, victim advocates and abuse survivors were consulted. There was an ongoing informal dialogue and exchange of ideas in relation to physical abuse and wearable technologies and how their intersection might address their needs. The *Wearable Witness* acts as a platform to test ideas about the intersection of wearable technology and abuse as wearable technologies begin to work their way into our daily lives.

The goal of the *Wearable Witness* is to examine the use of textile-based force sensors deployed in clothing in order to determine strategies for identifying physical abuse. In order to maintain the soft feel and pliable nature of fabric, the clothing incorporates textile-based pressure sensors which allow the garment to be comfortably worn. The sensors are wired into an embedded microcontroller capable of wireless communications intended for data collection. The force data can be viewable in near real time and can be archived for analysis.

The garment is designated into 7 distinct areas for sensing specific locations of the body: both left and right forearms and upper arms, back, chest and stomach **Figure 8**. The reason for separate sensor localities is partly due to body mechanics, but mostly for designating known impact areas during assaults. The classification purposes will be discussed later. Currently five sensors are implemented in the wearable, three cut specifically for body locations (forearm, upper arm and back) and two rectangular shapes that allow placement in the remaining areas to test various alternative sensor layouts.

The head and face of course are areas of interest. However an article published on Emedicine.com about emergency room injuries associated with domestic abuse stated that:

> *Among the most common sites of injury are areas usually covered by clothing* [45].

This is generally believed to be an attempt by the abuser to conceal the victim's injuries from the public view and is evident in child abuse as well. For our purposes the upper body and its extremities were a sufficient starting point.

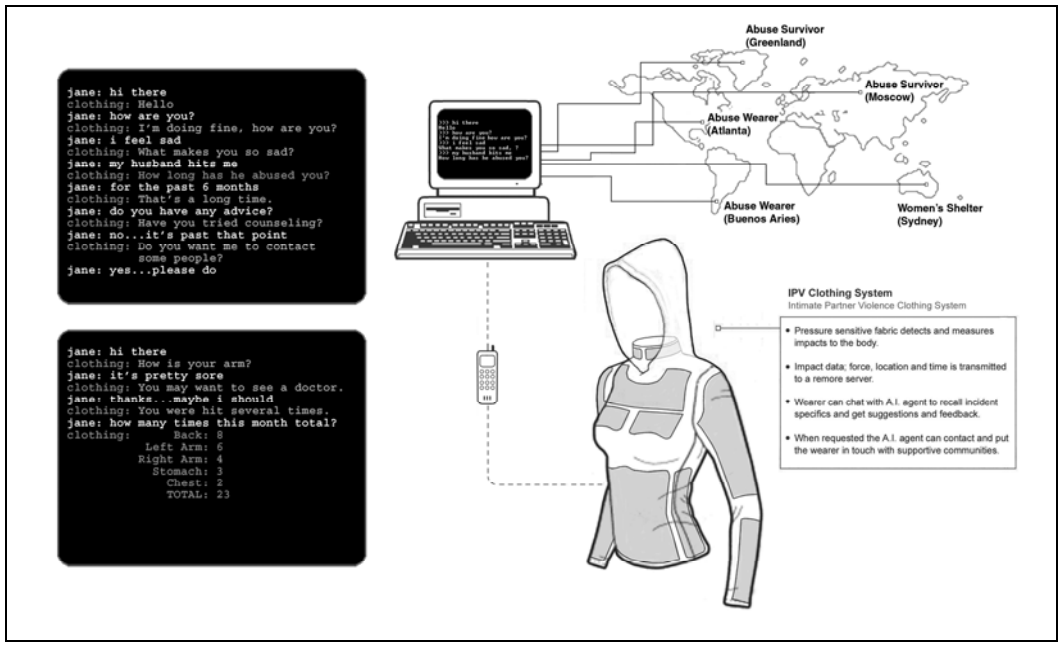

Figure 8. Diagram of communications and sensor layout for the *Wearable Witness*.

Each zone contains a pressure sensor to monitor and record the level of force, time of impact and location data of the forces experienced. The force data is transmitted wirelessly to any computer or mobile phone enabled with Bluetooth, and if connected to the Internet, could then send or share the data anywhere in the world.

6.1 Sensor Technology

While a lot of wearable work focuses on sensing the internal bio-physiological responses of the body for medical and emotional monitoring, the *Wearable Witness* specifically focuses on the external forces to the body as an absolute validation of physical abuse [28]. In order to cover a significant area of the body with sensing capabilities, a light weight, flexible sensor would be necessary. Quantum Tunneling Composites (QTCs) are

unique composite materials composed of metal powders and an elastomeric binder. The precise methods of doping used in their production alter the composite's electrical properties in a way that increases its conductivity when pressure is applied. They can be deposited onto various materials or be purchased in sheets.

In order to maintain the soft feel and pliable nature of fabric we used Quantum Tunneling Composites. Thin, flexible QTC sheets that are approximately .010 inches thick, were sandwiched between conductive fabrics resulting in a textile sensor approximately .025 inches. The assembly retained the feel of fabric allowing it to curve, fold and flex. It is easily cut into pattern pieces, sewn into garments and is washable **Figure 9** and **Figure 10**. The final assembly maintained fabric-like mechanical qualities, and this makes them suitable for a wearable system.

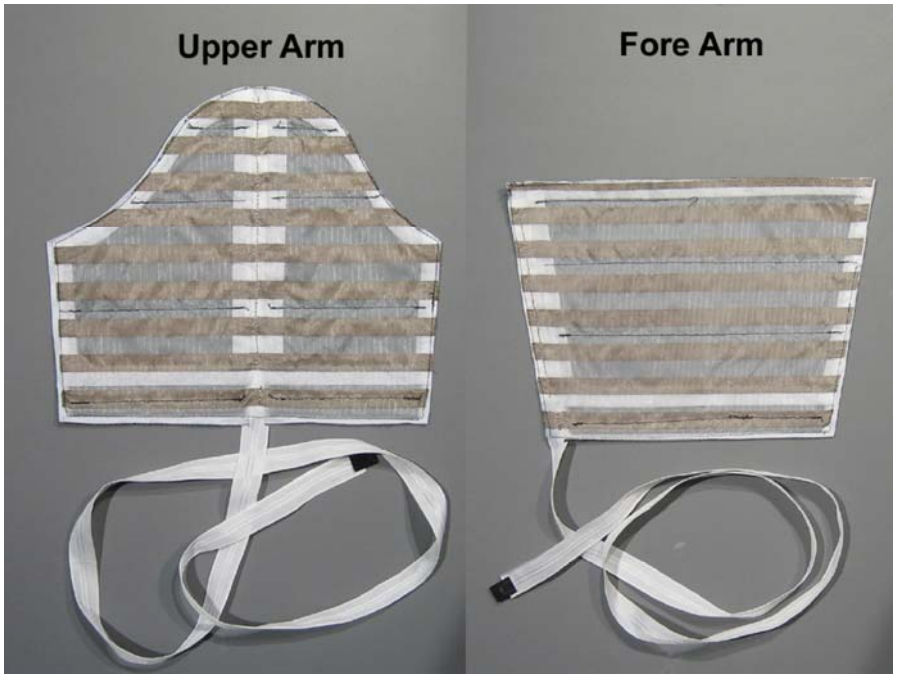

Figure 9. QTC sensors for the upper arm and forearm.

Generally, QTC sensors are produced with small areas, less than one square inch, whereas the sensor zones needed for this system can exceed 150 square inches in area **Figure 11**. Initial work and evaluation of this larger sized QTC sensor proved workable, although fine tuning of the sensors is needed. Because of the large size, properties of the QTC may vary from their smaller counterparts. These variations were evaluated. The large-area individual sensor elements were tested with stationary weights at rest on different locations of the individual sensor to check the overall consistency of the

pressure to conductivity ratio. For example the upper left quadrant of a single sensor might vary slightly from its lower right quadrant.

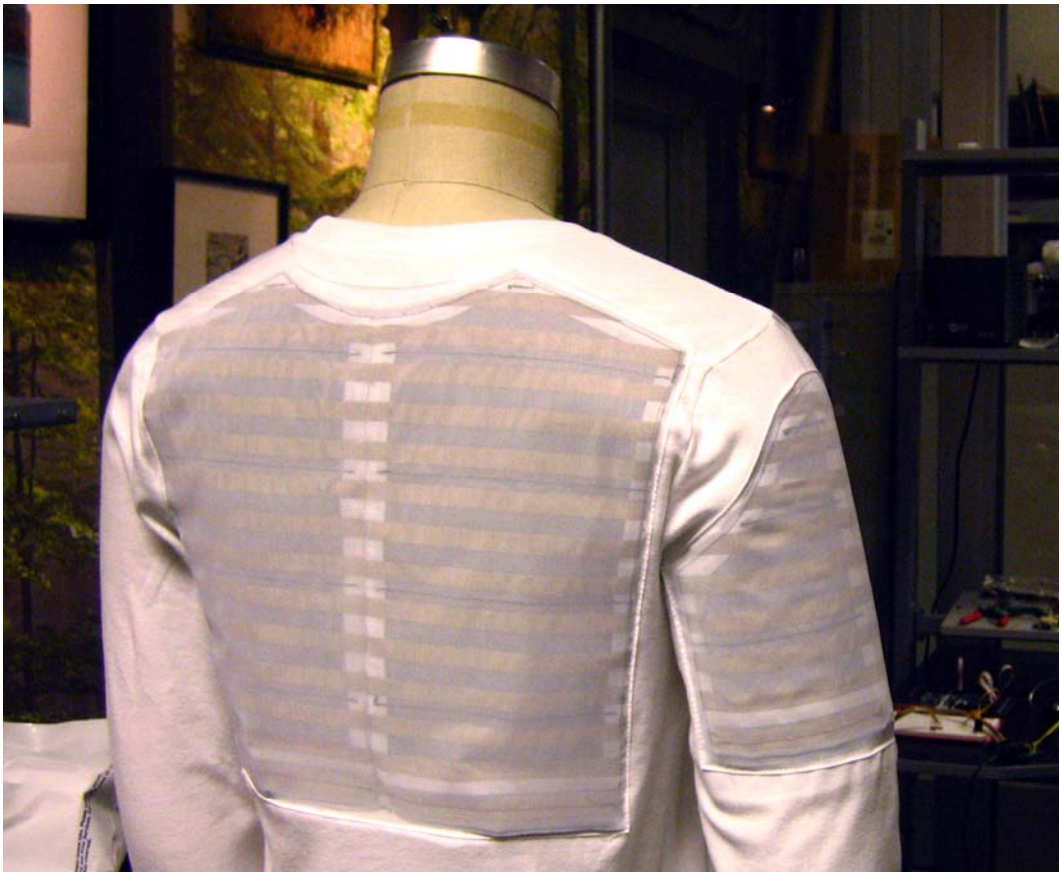

Figure 10. QTC sensors on the back and upper arm of the *Wearable Witness.*

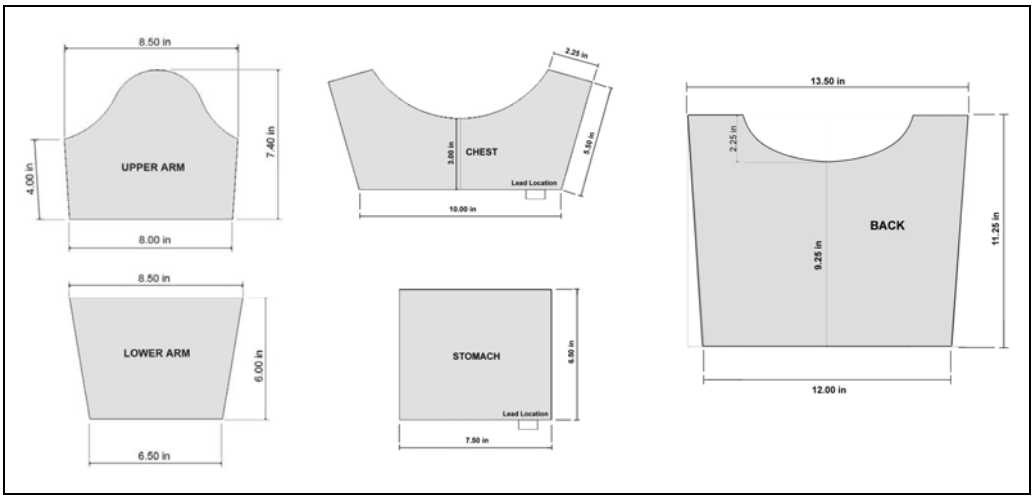

Figure 11. Patterns for sensor design: upper arms, forearm, chest, back and stomach.

Quantum Tunneling Composites (QTCs) are a fairly recent development and are currently proving useful as pressure sensors. They operate by exploiting the unique occurrence of quantum tunneling. Quantum mechanics differs considerably from the classical mechanics we experience every day. The following metaphor explains the quantum tunneling principle:

> *Consider rolling a ball up a hill. If the ball is not given enough velocity, then it will not roll over the hill. This scenario makes sense from the standpoint of classical mechanics, but is an inapplicable restriction in quantum mechanics simply because quantum mechanical objects do not behave like classical objects such as balls. On a quantum scale, objects exhibit wavelike behavior. For a quantum particle moving against a potential energy "hill", the wave function describing the particle can extend to the other side of the hill. This wave represents the probability of finding the particle in a certain location, meaning that the particle has the possibility of being detected on the other side of the hill. This behavior is called tunneling; it is as if the particle has 'dug' through the potential hill* [48].

Without pressure, the conductive elements, metal powder particles, are too far apart to conduct electricity. When pressure is applied, they move closer, just close enough for the electricity to take advantage of the quantum tunneling effect to tunnel across the normally insulating elastomeric. The result is a change in conductivity based on pressure. The quantum effect changes exponentially in relation to pressure as opposed to classical resistance which changes proportionally. Over the pressure range we were interested in the scaling did not cause any significant problems. When approaching around 400 N saturation of the sensor was observed although with further log scaling this could be resolved. A professional boxer's punch force is estimated at around 800 N although we felt this was beyond the capacity of the average untrained person and so our 400 N limits were deemed acceptable at this stage [29].

Each sensor was placed on a hard flat surface and connected to a digital multimeter. The electrical resistance of the sensor without any pressure applied was recorded. A 1.0 kg mass with a circular footprint of 50 mm diameter (resulting in a pressure of 509 kg/m2 = 490 Pa) was then placed on each quadrant of the sensor (top left, top right, bottom left and bottom right) and the resistance was again recorded. When a static load is placed on the sensor, there is a tendency for the resistance to take a short amount of time to reach a steady value. To standardize the testing procedure, the resistance was measured five seconds after the mass was placed on the sensor. The results of these tests are shown

in **Figure 12**. For each quadrant the resistance shown is the mathematical average of four tests.

Sensor	Quadrant	No Load	490 Pa pressure
Lower arm	Left top	8.8MΩ	113 k Ω
	Left bottom		112 k Ω
	Right top		108 k Ω
	Right bottom		85 k Ω
	Overall Average		**104.5 k Ω**
Upper arm	Left top	6.4MΩ	58 k Ω
	Left bottom		97 k Ω
	Right top		32 k Ω
	Right bottom		85 k Ω
	Overall Average		**68.0 k Ω**
Back	Left top	0.8MΩ	13 k Ω
	Left bottom		30 k Ω
	Right top		30 k Ω
	Right bottom		53 k Ω
	Overall Average		**31.5 k Ω**

Figure 12. Quantum Tunneling Composite Resistance table.

6.2 Microcontroller Development

The QTC sensor signals need conditioning, amplification and analog to digital conversion before they can be read or processed in the desired computational way. In order to achieve this, custom circuitry would need to be developed around an appropriate microcontroller platform that would be suitable for miniaturization and mobile applications.

The Atmel ATmega32 microcontroller of the AVR 8-Bit RISC series was chosen for this development because it is available in a small Thin Quad Flat Pack (TQFP) surface mount package and includes 8 channels for analogue to digital conversion. The board layout was done with CadSoft's EAGLE Layout Editor for designing printed circuit boards. The board was designed as a double-sided surface mount board to create a compact design capable of being incorporated as a low profile, non-intrusive component into clothing **Figure 13**.

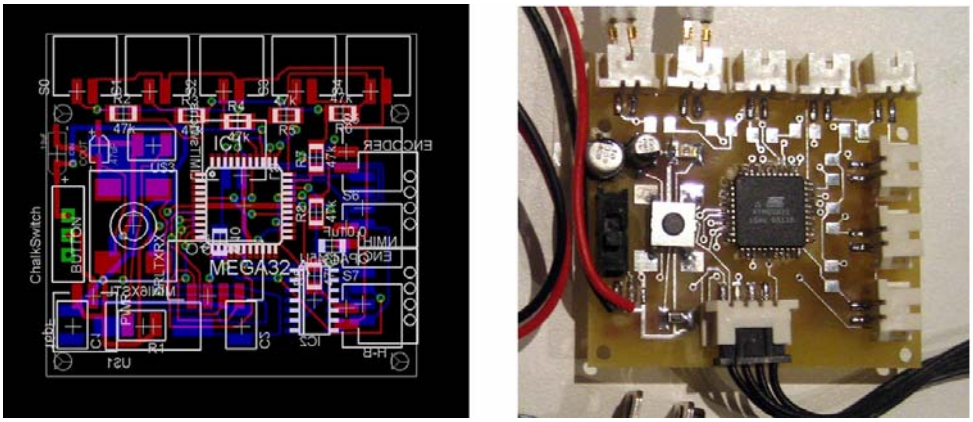

Figure 13. Double-sided printed circuit board layout and actual board.

The microcontroller board also incorporates the TLV2374 Quad Operational Amplifier to do basic signal conditioning of the sensor signals before being sent to the analogue to digital converters. Upon being impacted the output signal from a QTC sensor is first conditioned and amplified with circuitry built around the TLV2374. The signal is then sent on to the analog to digital converters.

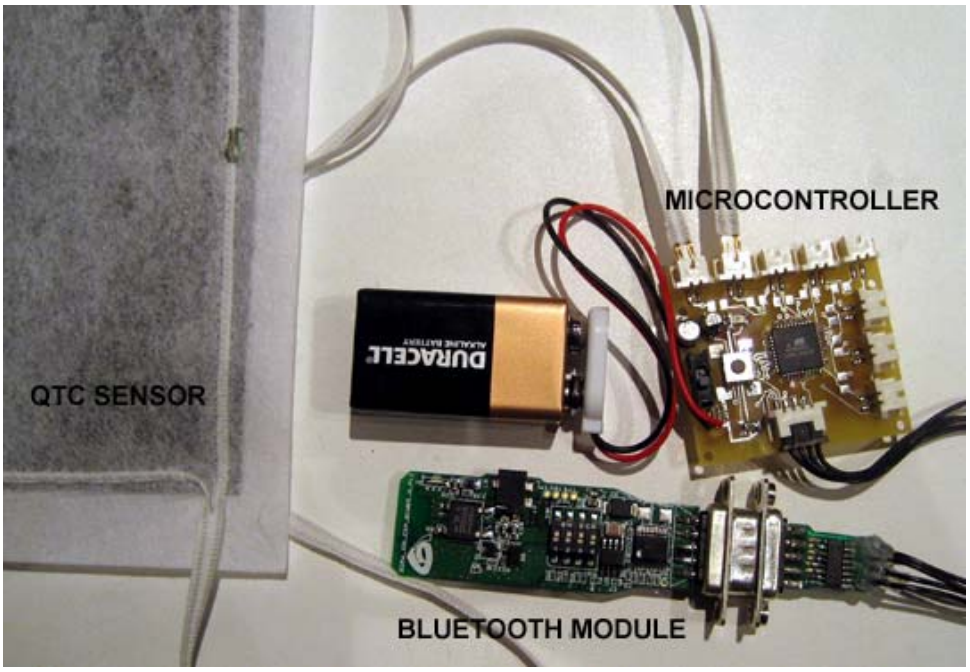

Figure 14. Atmega32 fabric board with Bluetooth module.

The microcontroller communicates via an RS-232 serial communication standard at a 57600 baud rate. This allows the microcontroller to communicate with other devices capable of serial communications including computers and many handheld devices like

cell phones and personal digital assistants (PDAs). The board can be connected with a standard serial cable to these devices or a wireless connection can be implemented. A Bluetooth module, compliant with 1.1 Bluetooth specifications and an estimated range of up to 100 meters communicating at the established 57600 baud rate was implemented allowing the garment to send data wirelessly to Bluetooth enabled devices **Figure 14**.

In one test a Nokia 6682 Smart phone was used to receive the sensor data. The Nokia 6682 is a Series 60 platform which is optimized for the Symbian OS and runs a Python 1.3.1 Interpreter. This allows us to access its data transmission and Internet connection capabilities by writing applications in Python. Ultimately a Bluetooth enabled laptop was used to receive and record the data transmission.

6.3 Characteristics of Abuse Data

Since wearable systems will become witnesses to abuse, how should they be prepared to identify such situations? How can we tell if the forces the *Wearable Witness* is experiencing are abusive? What characterizes a force as abusive? Without having contextual information about the environment or situation in which the force was applied, it is difficult to validate a force as abusive. Using the *Wearable Witness* as a platform for investigation, coupled with information from medical statistics and abuse survivors, we attempted to determine strategies for determining abuse in a wearable system. Through our observations we have identified four potential methods by which clothing-based force sensors might be used to detect defining features of abuse: *Waveform Identification, Intensity Thresholds, Body Mapping* and *Pattern Injuries*.

A pair of volunteers acted out abusive situations, one acting as the aggressor and one acting defensively. The forces used were greatly reduced from what might be expected in an actual confrontation. We wanted to ensure the participants safety, and we were predominantly interested in impacted locations on the body and interactions with the body rather than the maximum level of force. An apparel dress form was also used as it closely mimics a female upper torso and its padding is a rough equivalent to a body's soft tissue.

6.3.1 Waveform Identification

Although the forces were mild, we were able to identify increased levels of force and location on the body with our sensor layout. Based on visual observation of the output signals, we could correlate the generated waveforms with three distinct types of physical force: *Hits*, *Grabs* and *Shakes*. *Hits* or blunt impacts are marked by a brief punctuated

spike form; prolonged forces such as a *Grabbing* or restraining (arms and wrists) exhibit a slower increase and a plateau. Sometimes an initial spike is seen at the beginning. *Shaking* (arms) initiated as a plateau like form, but then pulsates up and down in a valley and trough wave form oscillating with the pushing and pulling of the arm **Figure 15**.

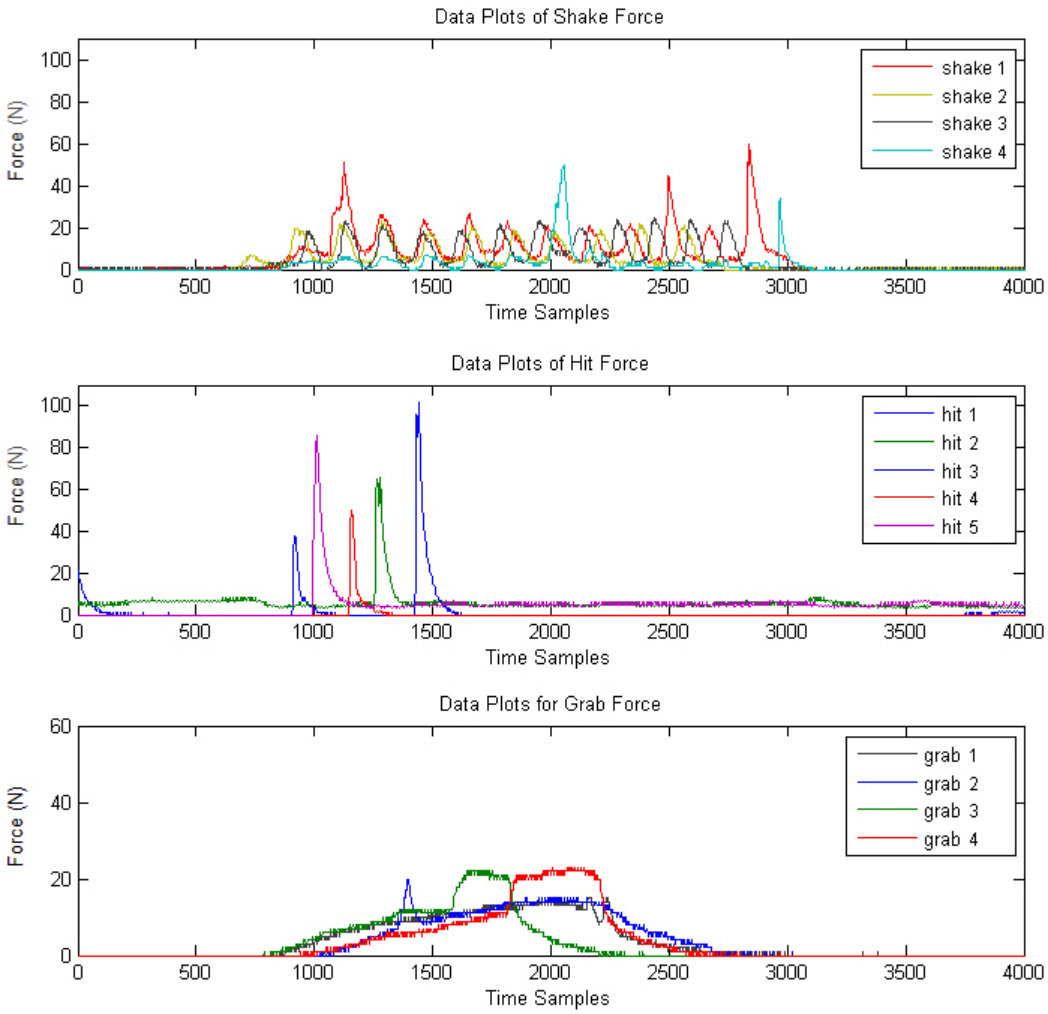

Figure 15. Initial force profiles from sensors. Shake, Hit and Grab.

The data was analyzed using MathWorks Matlab for plotting data and testing algorithms. A variety of pattern recognition methods were explored in an attempt to develop specific quantifiable features to discern between the three types of force signals observed. While discerning the difference between a hit and a grab might be useful in analyzing an abusive occurrence, it does not help in determining if that occurrence is being perpetrated by an abuser. It may act as one qualifier, but more potential qualifiers needed to be identified, so investigation of the signal processing was limited to peak and valley detection.

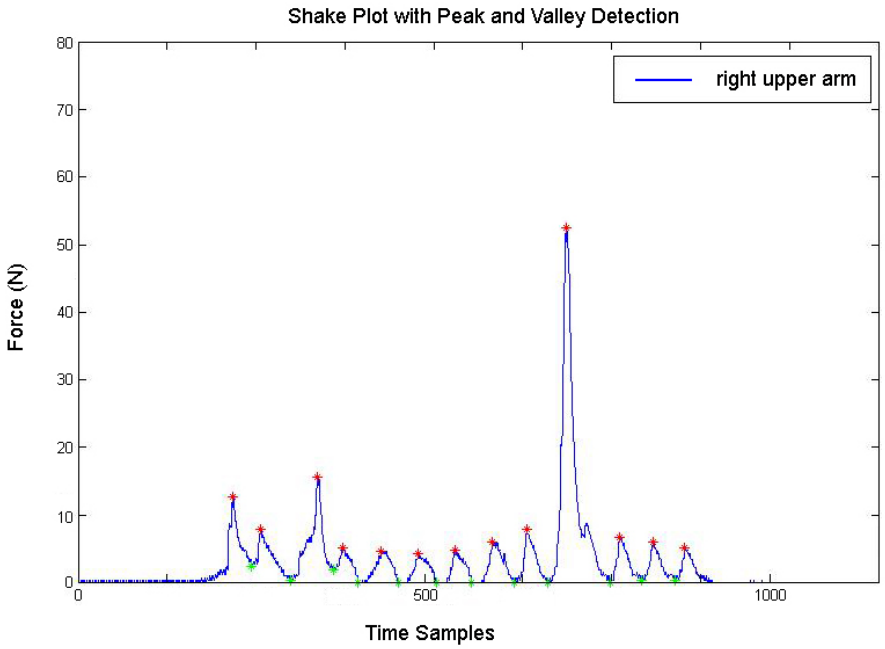

Figure 16. Red asterisks indicate peaks and green indicates minimums.

Peak and valley detection or maximum and minimum detection was important to develop in order to identify intensity of force as a qualifier of abuse **Figure 16**. If a force is of a high enough intensity, it can be considered to be dangerous and potentially injurious to the wearer and thus can be red flagged as potentially abusive. A customizable Matlab routine, originally developed by Eli Billauer, was used to identify maximum and minimum levels of force and provides adjustable threshold levels so lower level forces can be disregarded [5]. Intensity would be the prime factor for a system to identify physical abuse, but setting the threshold for such a system would largely depend on the age, gender and health of the wearer as everyone has different thresholds for injury and pain. Even within one's own body, certain areas are more vulnerable than others. Intensity of force deserves some closer examination and may require *"in field"* calibration for different groups of people.

6.3.2 Intensity of Force

The intensity of the force exerted on the body seems to be the most obvious factor in determining whether a force could possibly be abusive. A friendly pat on the back will register a significantly lower amount of force than an aggressive punch or kick. However, determining the actual threshold at which a force should be considered painful or dangerous and thus potentially abusive is a complex task. Various areas of the body have different thresholds for injury. In addition to a person's age, gender and health can

dramatically shift the threshold for injury. While no specific universal threshold can be determined, the mapping of various body locations and their associated thresholds for injury should be explored. This will help us better understand the broad scope of human tolerances to force.

For example, during strangulation approximately thirty three pounds of pressure per square inch is required to close the trachea or windpipe thus blocking the air flow to the victim's lungs. However, just a third of that pressure is needed to block the carotid arteries also located in the neck. Carotid arteries bring oxygenated blood to the head, neck and of course the brain. So in terms of the *Wearable Witness*, setting a threshold level on a neck area sensor for trachea strangulation might actually be too high for sensing carotid artery based strangulation.

When we consider the skeletal system and potential bone fractures, we see varying thresholds as well. For example, the cranial vault or top of the skull can fracture at 450 to 750 pounds per square inch; whereas the zygomatic arch, the side of the cheek bone, can fracture at only 150 pounds per square inch [21]. So within just the head and neck area we already see several different thresholds of force that would cause injury.

The fact that a force crosses the threshold for injury of a particular body part or location does not mean that it is an indication of abuse, but it does tell us that the force was potentially injurious. Although outside the scope of this thesis, creating an extensive body map of force intensity thresholds could benefit blunt force trauma sensing wearables. Potentially, those types of wearables could communicate with emergency medical services.

6.3.3 Body Mapping

Body maps are basically visual diagrams of the human body on which injuries or areas of pain and discomfort are marked in the appropriate locations. Body maps are used by physicians to mark a patient's areas of pain and by forensic physicians to indicate injuries to a body. The understanding is that once the individual injuries or symptoms can be located and viewed within the larger context of the entire body, the origin of the problem, or in the case of forensics, the cause of death might be revealed. There are in fact existing body maps for child abuse available to physicians, teachers and child care workers. These maps illustrate statistical probabilities of what bruises and marks should be considered potentially abusive based on body location **Figure 17**. For example, injuries to knees and elbows are quite common and tend to result from injuries during

play, while bruises to the buttocks or back thigh are suspicious of abuse. Location of injuries can reveal much information about how an injury might have occurred. Injured forearms tend to describe a defensive posture where a victim was holding up their arms to block being struck. In particular, excessive injuries to the left arm are possible indications that the attacker was right-handed; approximately 85% to 90% of the population is right-handed. So *Wearable Witness* recordings of frequent high forces to the forearms would be a cause for further scrutiny.

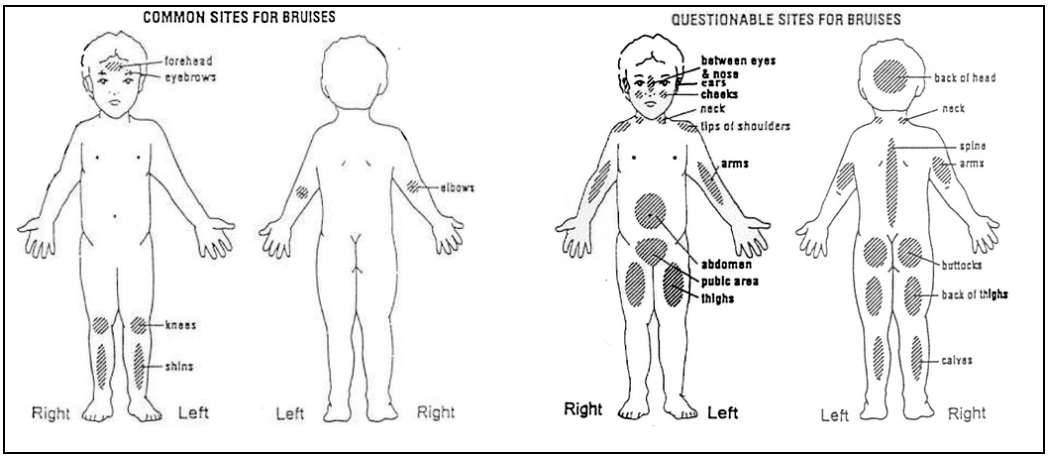

Figure 17. Body map for identifying child abuse.

The *Wearable Witness* is capable of going a step beyond static body maps by collecting real time data that could then create a temporal based digital body map. Because the garment would be worn during the actual abusive situation, the time of impact can be recorded in conjunction with the location. The *Wearable Witness* can generate data that could potentially produce an animated body map; one that can provide the number of impacts and the timing between those impacts as well as location so that temporal patterns could be observed. In essence it can provide a time-lapse re-play of the force events. With this type of time encoded data, we can look for temporal patterns consistent with abuse on a body map.

Because there is no previous temporal pattern data recorded from abusive situations, we have to develop these classifiers for abuse based on police and medical records. Salient time and location features of abuse include bilateral forces, multiple forces and the duration of the force event. Forces to multiple disparate locations, for example an impact on the stomach followed by an impact on the back at the opposite side of the body, are an indicator of abuse. Bilateral fracturing of the ribs is documented in abused children and results from forceful grabbing and squeezing.

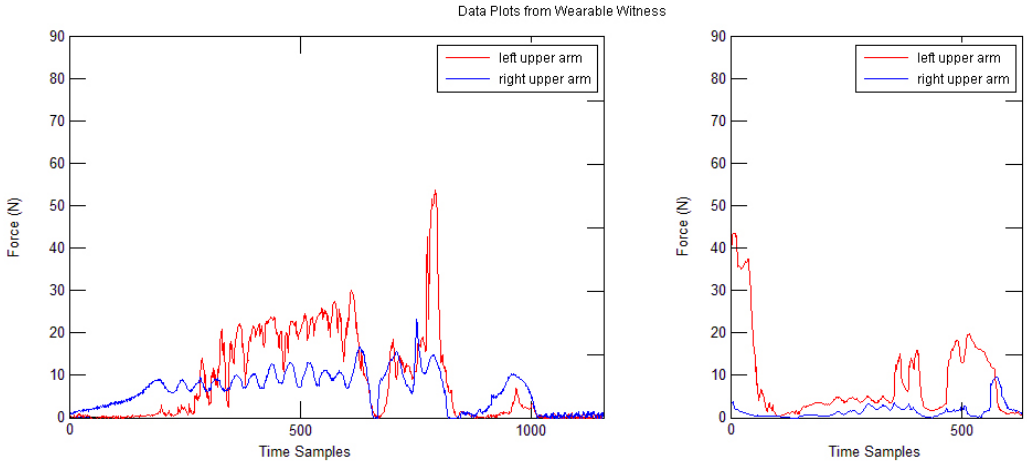

Figure 18. Bilateral forces recorded from left and right arms during simulated abuse.

In the simulated abuse sessions, we observed the volunteer abuser often grabbing the volunteer victim by the upper arms and then shaking the person. This was consistent with abuse survivor accounts and stories. Being grabbed and shaken presented a unique set of forces for the *Wearable Witness*. The recorded data from these sessions showed the grabbing and shaking forces on both the right and left upper arms in a synchronous oscillation **Figure 18**. The excerpts illustrate two classifiers; bilateral forces and the unique waveform of oscillation associated with shaking.

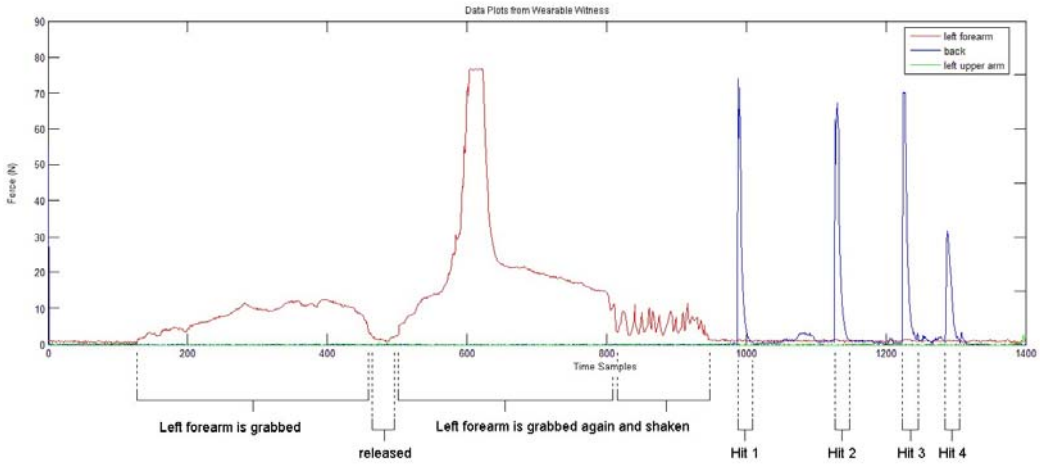

Figure 19. Data recorded from *Wearable Witness* during simulated abuse.

In another simulated abuse session, three sensors were active; the left forearm, left upper arm and the back. The left forearm of the volunteer was initially grabbed, briefly

released and then grabbed again but more forcefully. Their arm was then shaken but at this point the volunteer broke free and turned their back towards the volunteer abuser taking a defensive posture. The abuser then hit the victim four consecutive times in the back. The upper arm was not impacted or grabbed in this scenario and the recorded data measures near zero for the entire episode, which lasted approximately ten seconds or so **Figure 19**. When we reviewed the data we could observe a correlation between the simulated acts and the force waveforms and body locations recorded by the *Wearable Witness*.

With this technology, what might be visually observed as a singular large bruise on a victim could be determined to have been the result of multiple impacts to the same location which would rule out common excuses of *"I just fell"* or *"I bumped into something"*. A simple trip and fall would result in impacts occurring in a singular event lasting a second or two at most. A series of multiple impacts or force events lasting more than say five seconds would raise suspicion as it would represent a much longer event than a fall or a bump into an object.

6.3.4 Pattern Injuries and Forces

Bruising on the skin occurs when there is a significant amount of force applied to the skin to break the blood vessels. The shape of the bruise or contusion can reveal the type of object or weapon used to inflict the injury. These shaped bruises are called Pattern Injuries. Pattern Injuries are marks, designs or patterns imprinted on the skin by weapons. Pattern Injuries can have such distinct markings that the object used as a weapon is easily identifiable. Even the wave-like pattern of a coiled telephone cord or the braided pattern of a rope can be seen in strangulation markings. Clothes hangers and belts leave identifiable markings as well **Figure 20**. There are in fact several types of markings that can occur from abuse when the hand is used as a weapon. When slapped hard enough, the slap marks with delineation of the digits can be easily identified **Figure 22**. Small circular bruises 1-1.5 cm in diameter are consistent with fingertip pressure and may occur with severe grabbing. These marking will often be seen on the arms and specifically the upper arm area [45]. Excessive force with fingernails can result in scratch marks which appear as multiple long linear marks.

Figure 20. On left, a clothes hanger impression and on right, belt with buckle impression.

Figure 21. Bite marks and scratch marks left on body.

Pattern injuries consistent with weapons or hands can of course indicate abuse. As we can see in **Figure 21**, the body can retain the visual patterns of severe force in the form of bruises and markings, and these visual indicators can be used as evidence. The *Wearable Witness* can sense the force that might create these types of markings, but currently does not have the resolution to image the pattern of the object creating the force in the same way the body's skin naturally does. Other textile-based force sensing technologies such as those from the University of Bologna are beginning to achieve a high enough resolution to mimic this ability.

Figure 22. Pattern injuries on a victim of abuse, digits from a hand are easily identifiable.

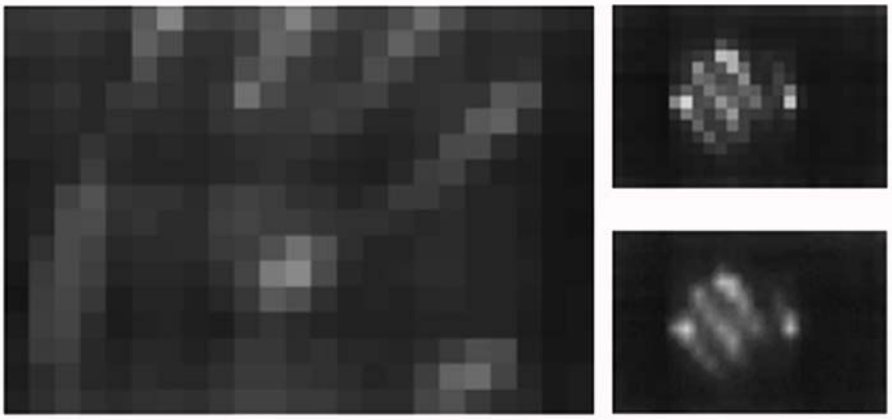

Figure 23. Results from the University of Bologna prototype showing hands.

The researchers at the University of Bologna created a 24-by-16 pixel sensor fabric prototype with an 8mm pixel pitch capable of producing an 'image' of the pressure field. As previously mentioned, a textile based capacitive pressure sensor was developed by creating a sandwich of conductive fiber columns and rows separated by an elastic synthetic foam. The elastic foam acts as a dielectric material and thus creates an array of capacitors between the columns and rows. When the foam is compressed, the coupling capacitance changes between the columns and rows of the textile [33]. The developers were able to update the pressure field image at approximately three frames per second. This level of resolution and refresh rate would be sufficient to determine certain types of pattern forces on a victim's body. The force images they achieved of hands would be appropriate to determine if excessive forces were perpetrated by another person **Figure**

22 and **Figure 23**. If objects other than hands were used as weapons, these too might be possible to identify if a collection of household items were categorized and their impressions or pattern forces recorded to a database for comparison.

In order to have a better understanding of how an array type sensor might be implemented in the *Wearable Witness*, an attempt at replicating the University of Bologna's work was made; the key difference being that the QTC acts as a resistive medium as opposed to the capacitive method used in their previous work. Using a conductive thread matrix stitched into an insulating fabric and a sheet of QTC material, I attempted to replicate aspects of the University of Bologna work. QTC material was sandwiched between two fabric layers that were sewn with a conductive thread matrix, 16 vertical rows and 16 horizontal rows. This provided 256 sensor points covering a 6 square inch area. This resolution was able to produce some recognizable features in the pressure images as compared with the object causing the force **Figure 24**.

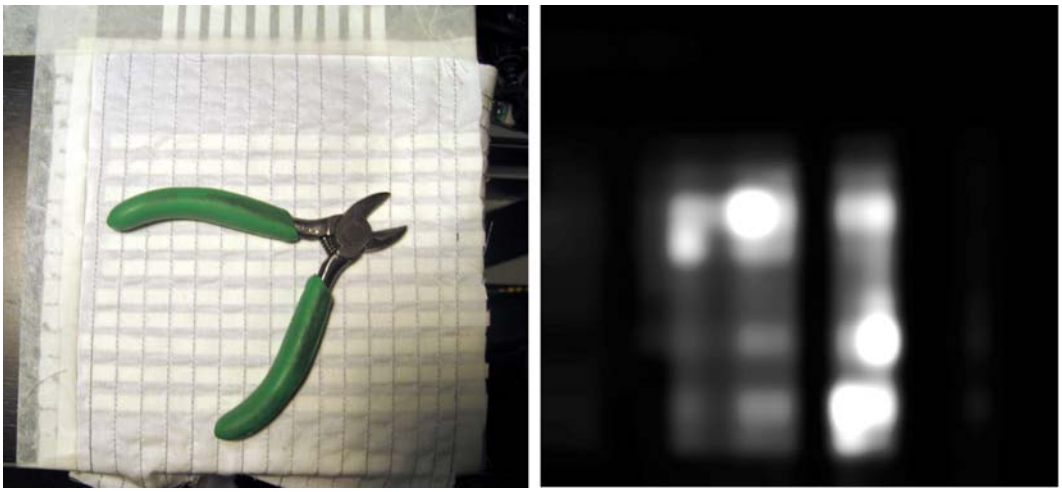

Figure 24. Pliers pressed into QTC sensing matrix and resulting pressure image.

A higher density of sensors would be ideal to image the full range of pattern forces on the body experienced during abuse. While a woven fabric array could produce such a resolution, the technology has not been developed to the point that a fully wearable application is possible. However, this seems like an ideal direction for future work. In terms of utilizing force data generated by human bodies to discern particular actions, we can look at previous work from Selene Mota and Rosalind Picard at the Massachusetts Institute of Technology Media Lab. They created force images of a seated participant in order to gauge the participant's level of interest while sitting and working at a computer work station. They used a pair commonly available Tekscan flexible matrix force sensors with a 42-by-48 array of sensor points. One matrix was located on the seat of the chair

and one on the back in order to map the pressure exerted on the chair as the person shifted their weight and position in relation to their interest on the computer screen. They were able to classify nine separate postures with an overall accuracy of 87.6%. This allowed them to further analyze the temporal patterns to determine three categories relating to levels of interest [22]. The *Wearable Witness* does not yet have this capability, as only one QTC sensor was developed as an array, but from the past work discussed here we can see that this type of direction could yield positive results.

We have examined several methods in which the forces exerted on the body can present indications of violence perpetrated by abusers. The intensity of the force can be used to tell us if the body is being subjected to excessive force that can cause injuries. Intensity would act as the first qualifier to raise red flags. Body mapping can provide us with the location and frequency of forces and when combined with statistical knowledge of abusive injuries can help to eliminate common accidental forces like falling down or bumping into furniture. Knowledge of pattern injuries coupled with textile-based force sensors that can create force images further assist in determining abuse. These force images can reveal shape characteristics of the instrument used against the victim. If hands or fists are visible, abuse will be highly suspected. Force sensing on the body provides several possibilities in identifying abuse, and further technical advances in textile-based sensors will no doubt increase the accuracy of these systems. Incorporation of other sensing techniques would add an additional layer of characterization. For example, a wearable biophysiological system geared to sensing anxiety and fear could act in conjunction with a force sensing system, and if a fearful emotional state was immediately followed by multiple excessive forces, then an identification of abuse could be made.

CHAPTER SEVEN

Critique and Evaluation

The evaluation will cover two main parts, the technical performance of the *Wearable Witness* garment and then its social role. First a technical evaluation of the system will be done to show whether the garment will function for its intended use. It will undergo simulated abuse situations as well as every day ordinary environments so a comparison of force sensing can be done. The second evaluation will focus on understanding its potential social impact. The work will be critiqued by a group of selected individuals who are actively involved in the abuse victim community. They will evaluate the work by reviewing the system in relation to their own experiences and those they have encountered.

7.1 Performance Evaluation

With a volunteer wearing the *Wearable Witness*, we conducted a series of sessions designed around typical daily activities. The object of this experiment was to observe the garment's performance and develop an understanding of the typical forces experienced by a person performing normal daily activities. The longest session lasted approximately two hours and the shortest around twenty minutes. Sessions included basic activities like walking and sitting as well as a more complex series of activities like getting into a car and driving, shopping at a mall and doing household chores such as the laundry. Data was recorded from the *Wearable Witness* using the Logomatic data logger and saved to an onboard flash memory card. The data collected from these sessions gave us a baseline of forces to compare to the violent forces experienced during our simulated abuse situations.

As described earlier, a pair of volunteers acted out abusive situations, one acting as the aggressor and one acting defensively. The forces used were reduced from what might be expected in an actual confrontation. We wanted to ensure the participants safety, and we

were predominantly interested in the interactions with the body and impacted locations rather than the maximum level of force. In a separate experiment, a padded form was used in order to gauge the intensity of force. The apparel dress form closely mimics a female upper torso, and its padding is a rough equivalent to a body's soft tissue. The form was hit and grabbed forcefully as one might expect to encounter during an abusive altercation. The simulated abusive situations combined with medical and forensic information on abuse and abuse survivor testimonies provided us a solid base of knowledge on abuse interactions with the body. The levels of force during typical daily activities did not approach those recorded during the intensity testing with the apparel form. This was generally expected but confirmed that a high level intensity of force could most definitely be used as one of the classifiers for abuse, as that level of force was unobserved in our typical daily force sessions.

7.2 Wearability Evaluation

The hoodie design was chosen as it represents a casual form of clothing worn by men, women and children of all ages and in all economic and social classes. The hoodie design covers the entire upper torso, arms and includes a hood. The hood could potentially be outfitted with sensors, although people do not always wear the hood up, particularly indoors, but there is the option. The base material the sensors are attached to is a French Terry fabric which is used frequently in athletic clothing for its comfort and breathability. In order to evaluate the wearability of the garment, we had five different women try on the *Wearable Witness*. The garment was designed for a dress size 8, as measured in standard women's apparel, and the participating women were within that size. The participants overall response was that the *Wearable Witness* was comfortable to wear, and the sensors did not cause any unusual feel. It was important to maintain the soft and pliable nature of clothing, and the electronics were the only rigid components of the system. The wearers noted that the electronics and battery did feel *"out of place"*, but thought that the components were compact enough. With some further miniaturization, and perhaps some light padding, we feel the electronic components could become less intrusive.

7.3 Social Evaluation and Critique

Recommendations derived from the observations and insights of those who work first hand dealing with abuse would be most valuable in evaluating the *Wearable Witness*. As a result of this, a group of two social workers and one abuse survivor were brought in to

critique and to evaluate the *Wearable as Witness* project. Participants in the group were not readily familiar with the field of wearables. They were shown several examples of other wearable technologies, and a brief history of the field was presented. They were then given a summation on the *Wearable as Witness* research, as well as demonstrations of the sensor technology. After the *Wearable Witness* prototype garment was presented, they were given the opportunity to interact with the garment and system.

One of their immediate reactions focused on the intimacy of sharing one's life with a computational object. The computational object, that is the wearable, begins to mimic its wearer's life experiences. The wearer may see various aspects of themselves transferred onto the wearable. The participants' concerns were that the boundary between object and wearer can blur, and for victims of trauma, could open up potential pitfalls in the form of Dissociation and Dissociative Identity Disorder (DID). Dissociation is a psychological state that victims of abuse sometimes enter into as a coping mechanism; in a way, the mind separates from the body. Some describe the feeling as *"leaving the body"*, or *"floating on the ceiling"* and viewing the abuse from outside of themselves. Trauma or situations of extreme stress can bring about dissociation behavior. So while some amount of dissociation is actually beneficial to a victim, too much may lead to Dissociation Identity Disorder. DID occurs when a single individual's separation during dissociation intensifies to the point that two or more distinct identities or personalities form, each with their own pattern of perceiving and interacting with the environment [46]. For example, a person's primary identity can split off a secondary identity that will exhibit completely contrasting characteristics. The participants' discussion focused not just on the *Wearable Witness,* but included the broader field of wearables when applied to victims of trauma. Wearables, because they are computational objects with their own sensors and programming, inherently have their own pattern of perceiving and interacting with the environment. That is precisely why a wearable is deployed; to do something we cannot do ourselves such as electronic sensing and computation. When it is applied to our bodies, for example with biofeedback systems or abuse sensing, we are in essence separating a part of ourselves, our experiences, into the wearable.

The topic of how the *Wearable Witness* might be distributed and in what venues generated a variety of opinions and possibilities. Concerns that a specific garment designed solely for sensing abuse might psychologically cast the wearer into a victim's mindset were echoed by the participants. However this concern was only expressed when discussing adults. When discussing so called vulnerable populations such as children or even the elderly in managed care, the participants could see how a *Wearable*

Witness garment could be utilized. Parents wanting to monitor the treatment of their child in daycare, or even older children on the playground, could be potential users of a *Wearable Witness* system. The Department of Social Services, having legal custody of abandoned children, could issue *Wearable Witness* clothing to those children while they are in foster care. In these scenarios, the evaluation group suggested that the clothing must be of a contemporary style and have no discernable differences from normal clothing in order to avoid the *"stigmata effect"*. For infants, this was less of a concern, and the possibility of a suit to monitor infants for signs of Shaken Baby Syndrome was thought to be of significant use.

In relation to children again, it has been found that children of abusive parents can grow up and become abusers themselves. In one sample of abusive fathers, 70% of them reported being abused as a child [18]. Children who witness abuse between parents will use that behavior to model their own future relationships. The abusive behavior can transfer from one generation to the next. Through the course of the discussion this point was raised, and it was suggested that perhaps a *Wearable Witness* garment could be used as a teaching tool for children and adolescents. One participant had repeatedly observed young adolescents in school settings acting physically aggressive with members of the opposite sex, and noted how some of this behavior could be from observing abusive parents. It was suggested that using the *Wearable Witness* garment with a data visualization setup could help illustrate the differences between a soft or appropriate touch, and one that is too hard or aggressive. Visualizing the difference between a hug and a hit could make for a powerful learning experience.

Although the participants tended to focus on applications involving the protection and education of children, uses for adults were discussed as well. They did see potential for a *Wearable Witness* garment to be utilized in private therapy, particularly in conjoint therapy sessions, in which the victim and abuser both see the same therapist. Conjoint therapy with spouses involved in abuse is very controversial and is actually illegal in some states, but it does take place. It requires that physical abuse absolutely has to cease in order to start any type of conjoint therapy, and must remain in check for the sessions to continue. In these situations the *Wearable Witness* could be worn and act as a third party deterrent to the abuser. In this case, the abuser is fully aware of the *Wearable Witness* and its capabilities to sense, record and remotely report.

The participants agreed that if abuse sensing was seamlessly integrated into other future smart clothing or wearables that find their way into the consumer market, then victims

would access these abilities for their own therapeutic rationales, much like the phenomenon observed in the Sims™ Photo Album discussed previously.

The preliminary finding of the performance evaluation shows us that the *Wearable Witness,* abuse sensing in a wearable form, is possible. The intensity classifier for abuse has been tested on this platform with encouraging results. The social evaluation and critique highlighted the significant psychological impact wearables in general might have on those individuals who have experienced trauma. In addition, the differences between children and adults as potential users were highlighted as an important design guideline. Aside from the potential risks, there exists the potential for the *Wearable Witness* to be utilized as both a therapeutic and educational tool in the realm of abuse. Because these victims can exhibit dissociative tendencies, perceptions of themselves as victims and the social bias of society, caution must be taken in the design and implementation of such a system to take into account their needs and fragilities.

CHAPTER EIGHT

Conclusion

The *Wearable Witness* project is intended as a surveying stake to demonstrate a possible field of future investigation. The project explores the realm of abuse and technology as it pertains to the field of wearables, and the unique relationship technology and the body share. We have presented the hypothesis of an existing technological arms race between victim and abuser, and demonstrated the need for researchers to be conscientious as to how their technologies might influence that dynamic. The *Wearable as Witness* project lays both the theoretical and technological groundwork for abuse sensing in wearables. We have identified and trialed wearable textile-based sensors that sense forces exerted on the body, and constructed a physical prototype to test our ideas. We have examined medical and forensic evidence of physical abuse and discussed strategies by which wearables and machines might come to identify such abusive patterns. The evaluation critique with the social workers and abuse survivor provided valuable insight that uncovered the potential ethical difficulties in developing wearable systems for those suffering psychological trauma and the differences between adult and child victims.

Wearables will eventually be indistinguishable from our ordinary everyday clothing, except for the fact that they will be taking an active role in meshing our bodies and lives into larger information systems. Technology's role in being socially responsible should evolve alongside its increased intimacy in our lives. Researchers and designers should take an active position on developing technologies for communities that most need the assistance, not because technology can solve all their problems, but because technology can act to empower. It is my hope that this thesis can act as a set of guidelines for future work in which the use of wearable technology attempts to tackle difficult but critical social issues.

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